DEEP UNDERGROUND NEUTRINO EXPERIMENT

# Future TDAQ

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Module of Opportunity Workshop

Brookhaven National Laboratory

12 November 2019

Science & Technology Facilities Council
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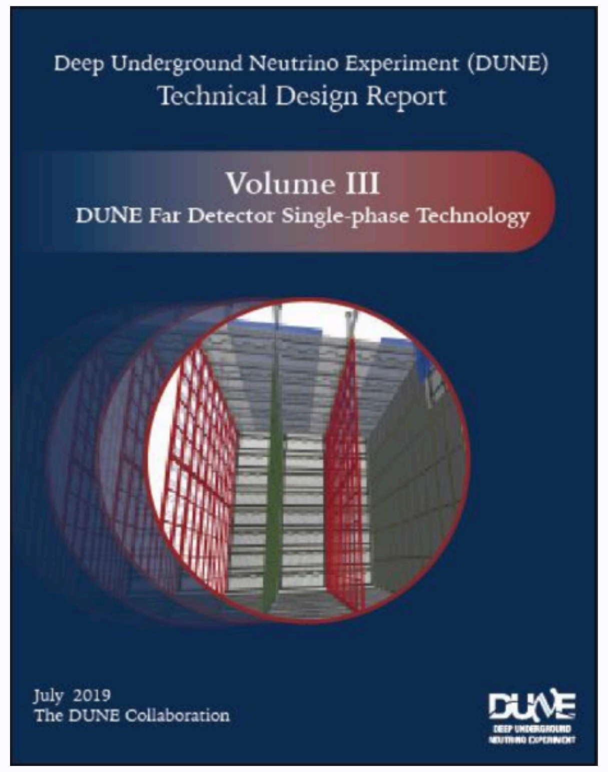
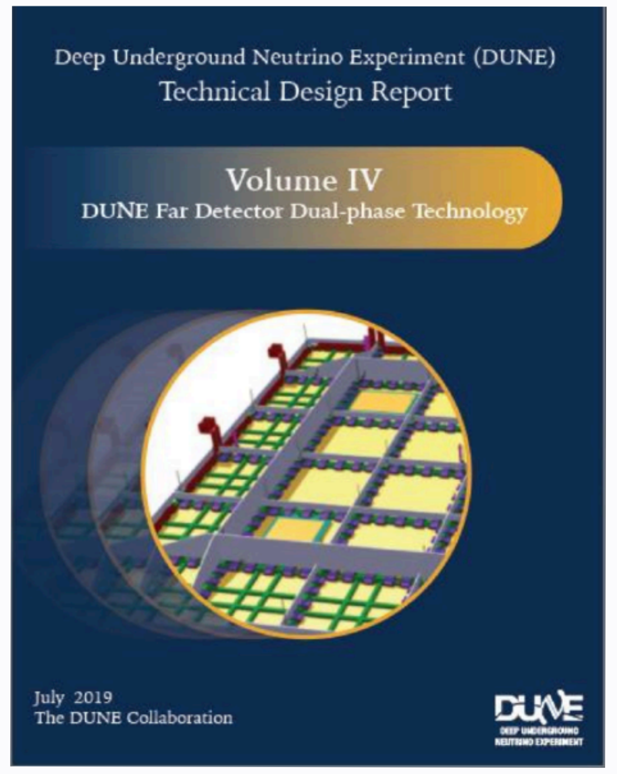
# Outline

- DAQ for the Module of Opportunity
- Self-driving DAQ
- Continuous readout
- Machine-learning-based data-selection

# DAQ in the context of the Module of Opportunity




- **DAQ mission: collect the largest amount of physics data within the experiment's cost, bandwidth, storage constraints**
  - Joint design joint for SP and DP technologies, detailed in TDR vol. III & IV.
- **MoO: Location and complexity of a large-scale underground experiment unchanged w.r.t modules I, II and III**
  - Remote access, limited space, power & cooling restrictions.
- **Operating a 10+ kT class LArTCP detector will be a well-established practice**
  - Extensive experience gathered with module I-III.
  - Not just operations but installation and commissioning.
    - Environmental conditions, noise levels, backgrounds, etc…

# Module of Opportunity DAQ

- **Discussing the details of trigger and DAQ before defining the detector technologies is a somehow theoretical exercise**
  - Single/Dual Phase? Projective Charge Readout? Pixelated charge readout? Etc…
    - All sorted out by the end of the workshop!
- **Detector technologies determine most of the TDAQ parameters**
  - Timing precision requirements, data reduction levels, compression, total throughput, triggering and data-selection algorithm, etc…
- **Some aspects remain relevant regardless of the subsystem/sub-detector choices**
  - Readout building blocks, **data-flow**, storage, and **data-selection** technologies, synchronization and synchronous time and command distribution systems
  - Supervision and automation of data taking – Autonomous Control Configuration and Monitoring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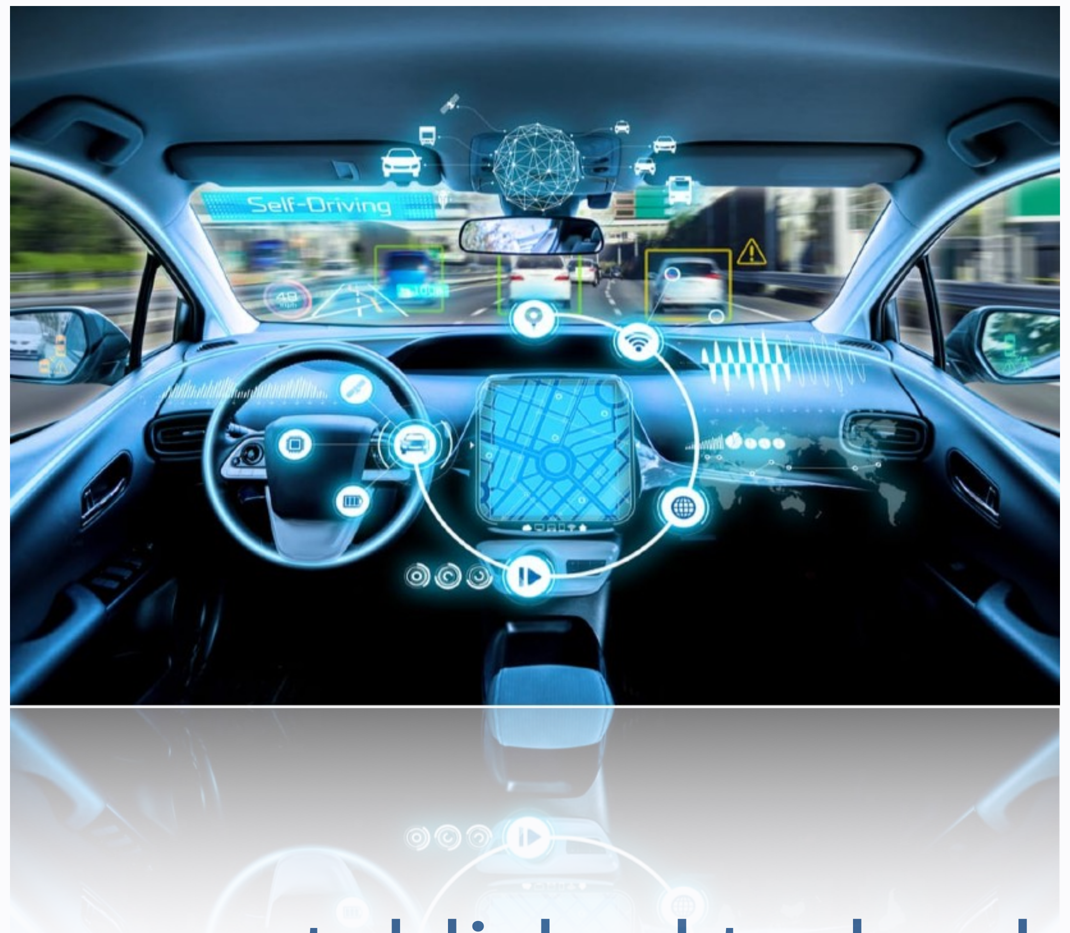
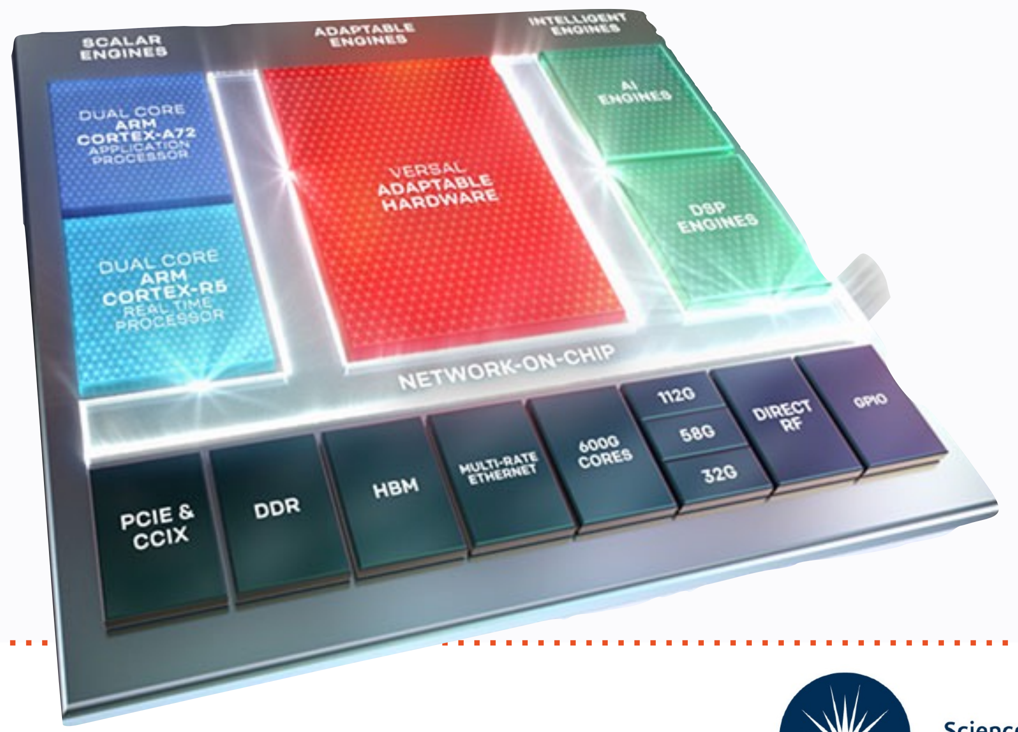
# What the future holds for the DAQ?

- **Evolution of IT/Com technologies plays in DAQ's favour**
  - Continuing to leverage on COTS solutions grants access
    - Memento: DAQ is designed last and installed first.

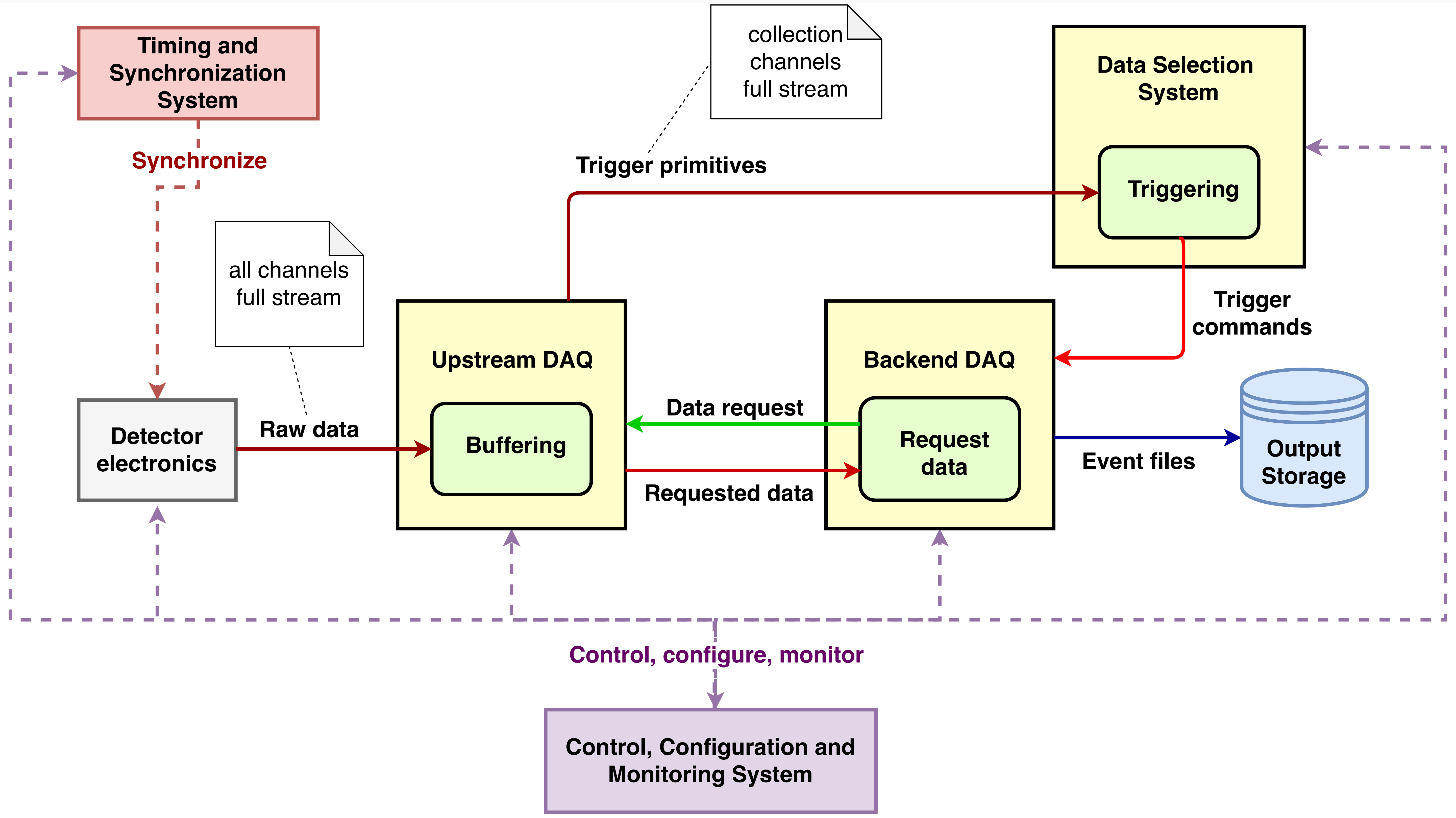



- **In particular**
  - The autonomous system nowadays in development are likely to be an established technology (automotive industry).
  - FPGA market shifting towards Machine-Learning based application with highly integrated solution,
    - New opportunities on for complex, highly-selective algorithms running very close to the detector.



# Automation

# CCM in a nutshell




Connections between CCM and DAQ subsystems.

<-- Commands and configurations

--> Monitoring data, events and errors

- **Software subsystem that steers data-taking operations**
  - Controls DAQ and non-DAQ components participating to data taking
  - Stores, manages and distributes the configurations of the whole system
  - Monitors the status of all components
  - It is responsible for error handling and recovery

**Primary goal:**

**Maximize system up-time, data-taking efficiency and data quality**



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# Towards Autonomous DUNE DAQ

- **The CCM is currently conceived for manual interaction with aspects of automatic error detection, recovery and scheduling**
  - The operator is always in charge, approves or reject any change of course
  - Automation limited to simple actions, e.g. isolate a problematic component (recover a channel, exclude APA X)
    - In modern vehicles, this is akin to ABS, or rain-sensing wipers
- **Module of opportunity : quantum leap to truly autonomous data-taking?**
  - The CCM only interacts via very high-level commands. Decides the best course of action to acquire the requested data
  - The shifter doesn't start/stop runs, it oversees data-taking
    - In the automotive example: fully self-driving car "drive me to my to the coast and put on some relaxing music. Book a nice restaurant on the way if the traffic becomes to heavy"

# Towards Autonomous DUNE DAQ (II)

- **This is by no means a trivial challenge**
  - The two are inherently different
  - That's why we're still talking about self-driving cars after 50 if not 100 years

- **Such a system is only conceivable with a full integration between the Detector Controls (SC) and Trigger/Data Acquisition**
  - **On-the-road experience fundamental** – module I, II and III will be key to consolidate interfaces, identify procedures, develop an in-depth understanding of the interactions.

# Dataflow

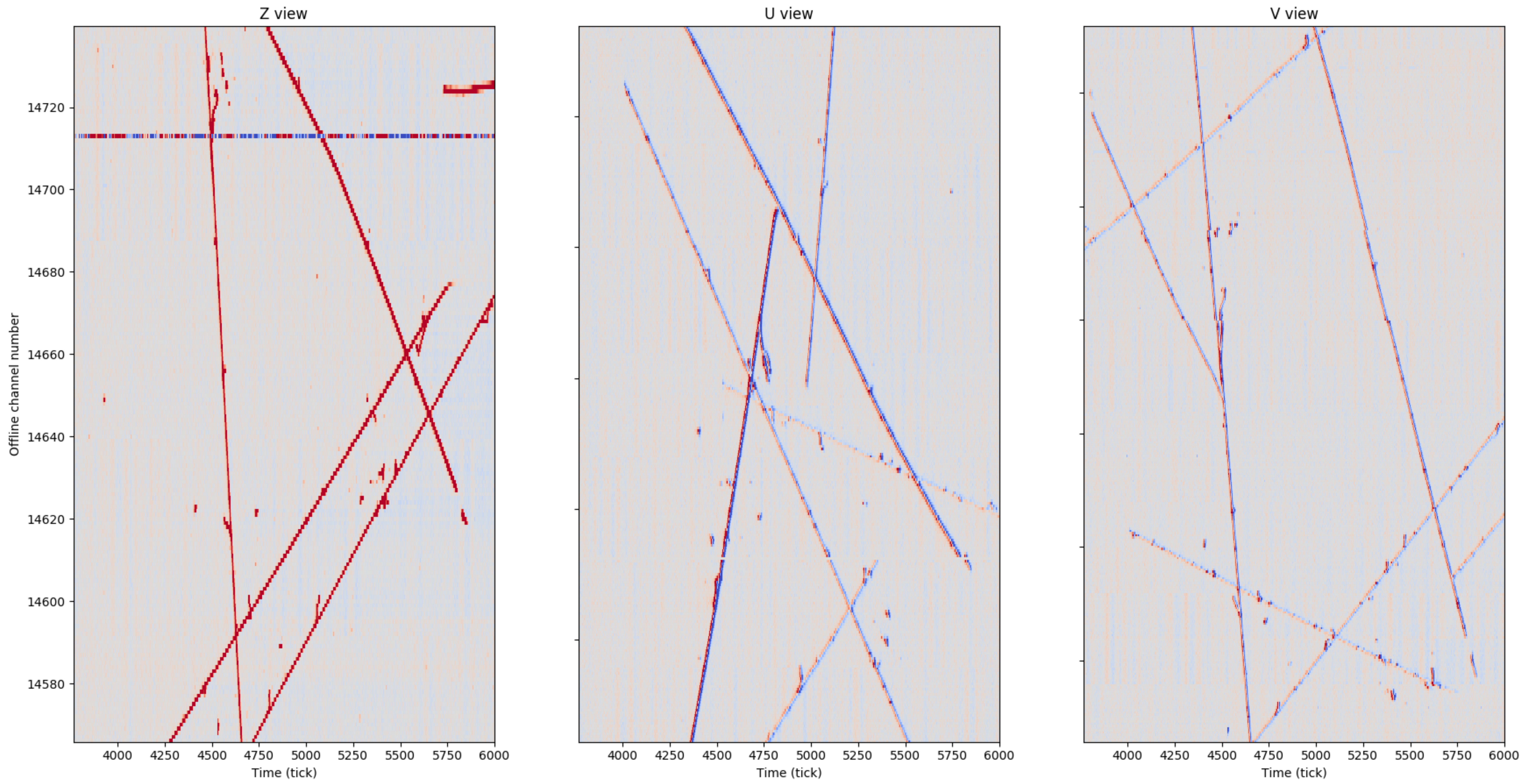
# Increasing Possible ways forward?

- **Save everything to tape**
  - Every charge/light deposit above noise threshold is tagged, stored and transferred to offline for later analysis
  - Apply early data reduction in the DAQ readout chain
    - What to drop, what to keep? ROIs? Selective readout? Zero suppression?
    - What is the right balance to between data reduction and bandwidth to maximise the physics yield?
    - How to handle an unstructured stream of interactions?
- **Write the next discovery paper directly in the fronted**
  - Include physics quantities into the output data, calculated during DAQ processing
    - Eventually, store no RAW data at all (except for a highly pre-scaled unbiased control sample)

# Continuous data readout & storage

- **Currently foreseeing an extra-conservative readout strategy for the initial days of the first module(s)**
  - 384000 readout channels @ 2 MHz for 5.4 ms -> 6 GB/trigger in SP (worst-case scenario)
  - Sub-Hz readout rate
- **Straightforward to reduce the readout to APAs/CRTs where the activity is confined**
- **Can we go even further?**
  - Even in ProtoDUNE, at ground level, the bulk of recorded data is noise
    - And DUNE will be much quieter…

# ProtoDUNE SP event example




- Despite the large activity in this event, the disk footprint is dominated by empty samples

# Continuous data readout & storage (II)

- **Region of Interests readout (in wire X time) around detector activity could shrink the size of stored data by orders of magnitude**
  - Close collaboration with computing and reconstruction to determine the optimal reduction strategy is essential
  - And allow much higher trigger rates than currently foreseen in DUNE
    - Giving access to low(er)-energy physics
    - **New strategies for trigger distribution and event building**
  - Pushing the concept to the extreme: is trigger necessary at all?
    - If so, without the concept of trigger, how can un-structured streaming data be stored?
    - **Distributed file systems? Key-value stores?**

# Dataselection

# Real-time analysis for data reduction

- Software-based data selection (DS) taking advantage of recent developments in **machine learning** can be implemented in next-generation CPUs or GPUs, providing flexibility and re-configurability for online data selection, but perhaps at the cost of increased latency and power consumption.
- The possibility of **hardware acceleration of machine learning algorithms for low-latency, real-time applications involving large data sets** is an exciting new development enabled by new technology and tools:

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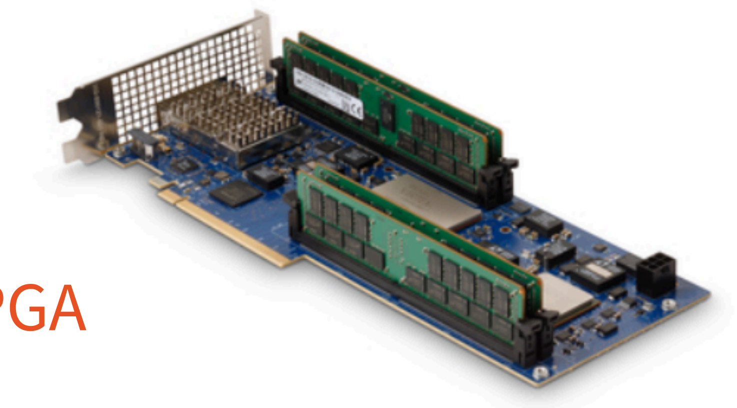
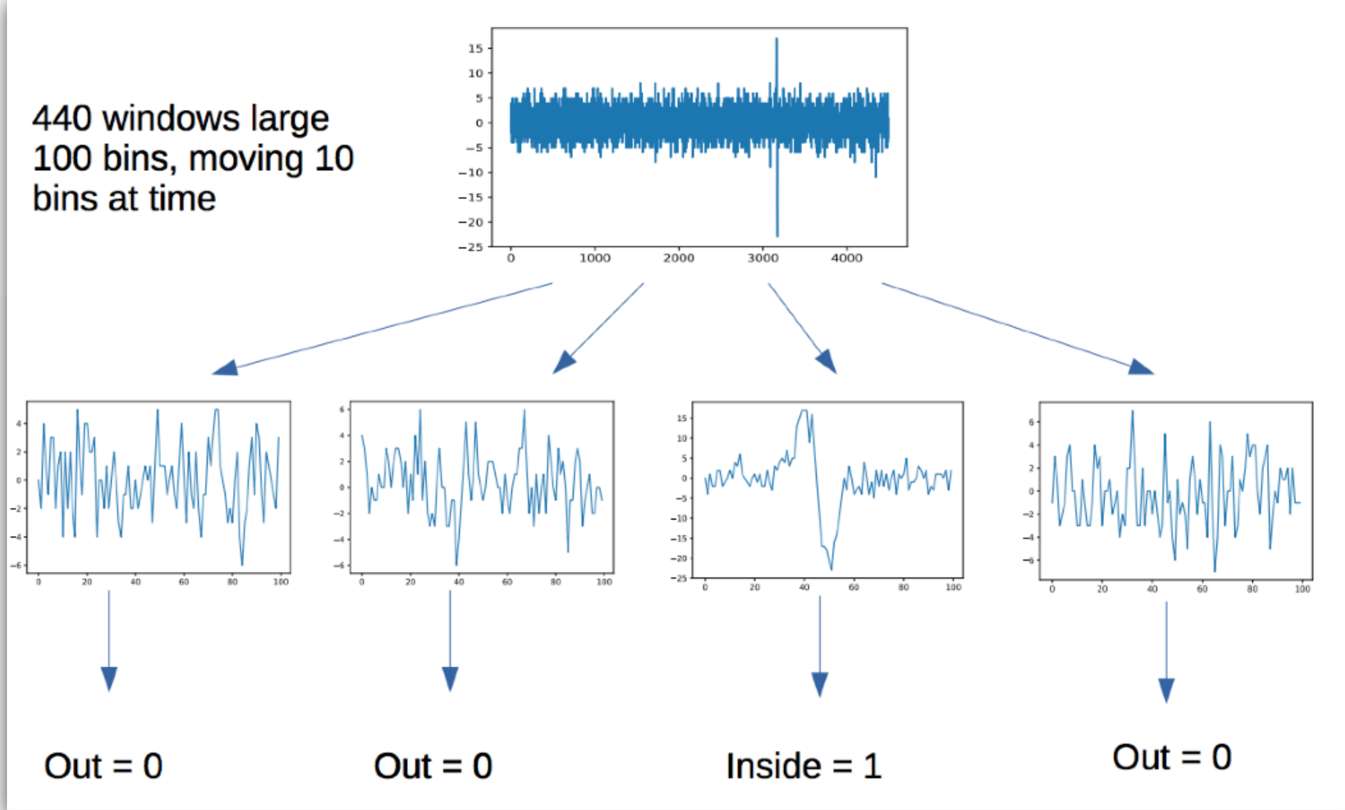


Increasingly more powerful FPGA

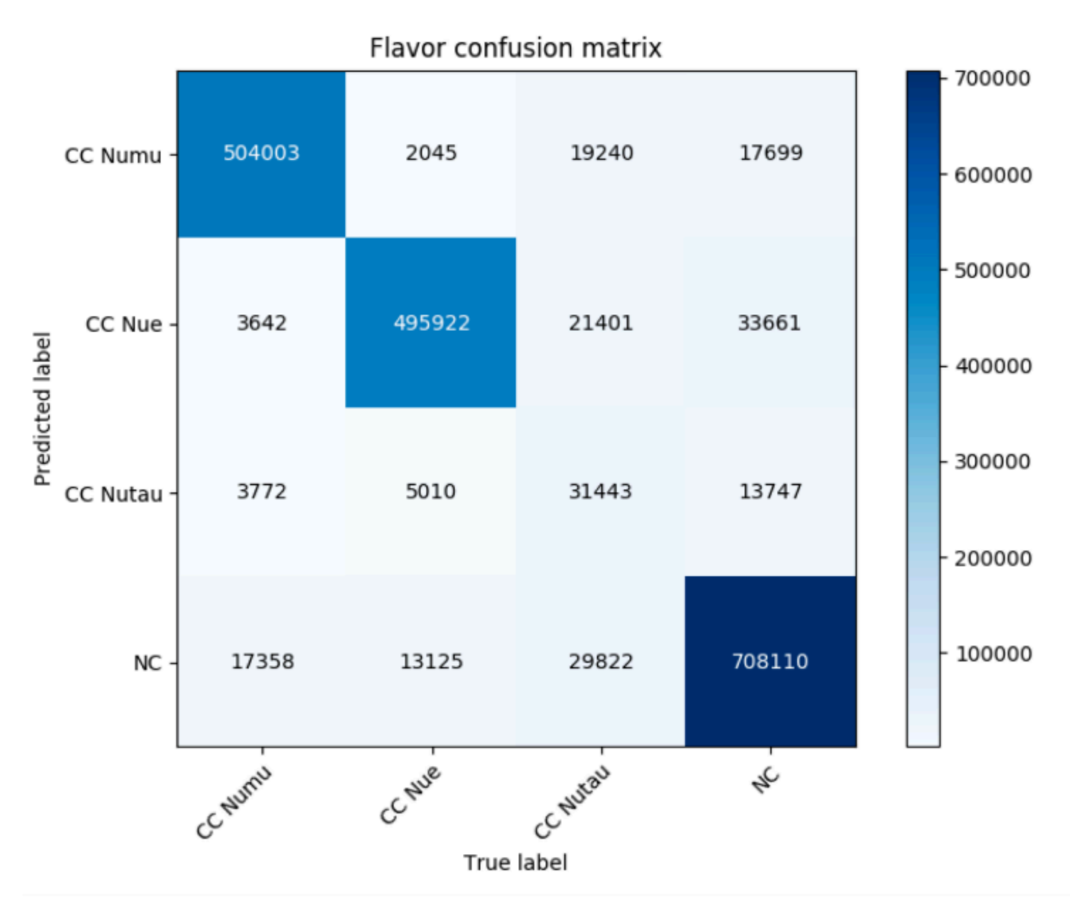
- Such **R&D efforts are already being pursued** within the DUNE DAQ Consortium; the developed techniques are **transferable to other detector technologies** involving "streaming DAQ" systems and/or imaging detectors.

# ML methods for DS




**What is being explored:**

- 1D DNNs operating on a per-channel basis, classifying signal vs. background activity
  [M. Wang, L. Uboldi, J.-Y. Wu, *et al.*, Fermilab]




[CPAD2019]

Image classification using DNNs operating on a channel vs. time (2D) basis, classifying, e.g.:

- Preselected image topologies (e.g. neutrino interactions during beam spill)
  [P. Sala, M. Rodriguez, CERN]
- Images of noise vs. types of rare off-beam physics activity (supernova neutrino interactions, proton decay, etc.)
  [G. Karagiorgi, Y. Jwa, L. Arnold, *et al.*, Columbia U.]

| Sample | Train Size | Test Size | Accuracy (%) $\epsilon_{NB}$ | Accuracy (%) $\epsilon_{LE}$ | Accuracy (%) $\epsilon_{HE}$ | Inference Time (ms) |
|---|---|---|---|---|---|---|
| NB | 12,023 | 4,027 | 99.53 | 0.47 | 0.12 | |
| LE | 12,050 | 3,970 | 4.01 | 94.48 | 1.51 | 1.6±0.1 |
| HE | 10,137 | 3,417 | 3.63 | 6.15 | 90.22 | |

[IEEE Proceedings to NYSDS'19]

# Fast ML

- Offline performance of these algorithms shows promise, as it continues to be benchmarked against continually improving simulations.
- Online inference seems realistic, for an experiment of the scale of DUNE (streaming data of multi-TB/s), and efforts now are focused on real-time implementations and demonstrations.

# Conclusions

- **Module of Opportunity DAQ**
  - still remote, of difficult access, constraint by power, cooling and bandwidth
- **The detector technology choice will define many of the DAQ parameters**
  - together with the experience matured on modules I-III
- **Technology evolution plays in our favour**
  - Evolution of autonomous systems
    - Maximize system up-time, data-taking efficiency and data quality
  - Storage of large quantities of unstructured data
    - Continuous readout & storage
  - Highly refined feature extraction and event identification in real time
    - “On-detector” rare events searches

# Backup

# DAQ System Layout